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Design of Wireless Power Transfer System

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Tesla Tower concept
magnetic coupled circuit
magnetic resonant coupled circuit.

ABSTRACT

In the recent years of the twenty first century, the world has witnessed a noticed evolvement in wireless techniques, such that wireless phones, wireless electronic devices, wireless communication and wireless power transfer. Wireless power transfer is a modern technique used to transfer an electric energy from a source to a destination that is consumed to the load. Wireless power transfer is an important for many applications like, wirelessly powered home appliances that received the power from a transmitting device wirelessly. For example lighting of bulbs, operating of electric equipment and wireless charging for electric tooth brush and charging mobiles. In the developed countries there is wireless charging of electric vehicles is based on magnetic resonance field as in Japan. Based on this concept , the idea of this paper has been chosen. This paper aims to design a wireless power transfer system. This design has accomplished three tasks: one is to build a Tesla Tower design circuit and measuring the possible efficiency can be obtained. It's got satisfied results to about 70%. The second task is to build a magnetic coupled circuit that is based on the idea of wireless mobile charging technique. During our work, it's studied the power efficiency and its related to the distance between transmitter and receiver, the diameter of the coils and number of turns. To enhance our results, it's suggested to connect and design of these circuits by simulation using Multisim software and get the desired goal.

تصميم نظام نقل الطاقة لاسلكيا

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الكلمات المفتاحية:
نقل الطاقة لاسلكيا
مفهوم تسلا تور
الدوائر المقترنة مغناطيسيا
الدوائر المقترنة مغناطيسيا بالرنين

الملخص

في السنوات الأخيرة من القرن الحادي والعشرين، شهد العالم تطورًا ملحوظًا في التقنيات اللاسلكية، مثل الهواتف اللاسلكية والأجهزة الإلكترونية اللاسلكية والاتصالات اللاسلكية ونقل الطاقة لاسلكيًا. نقل الطاقة اللاسلكي هو تقنية حديثة تستخدم لنقل الطاقة الكهربائية من مصدر إلى وجهة حيث يتم استهلاكها للحمل. يعد نقل الطاقة اللاسلكي أمرًا مهمًا للعديد من التطبيقات مثل الأجهزة المنزلية التي تعمل بالطاقة لاسلكيًا على سبيل المثال إضاءة المصابيح وتشغيل المعدات الكهربائية والشحن اللاسلكي لفرشاة الأسنان الكهربائية وشحن الهواتف المحمولة. في البلدان المتقدمة يوجد شحن لاسلكي للسيارات الكهربائية مبنيا على فكرة دوائر الرنين, بناءً على هذا المفهوم ، تم اختيار فكرة المشروع حيث يهدف هذا المشروع إلى تصميم نظام نقل طاقة لاسلكيا , هذا التصميم ينفذ مهمتين :

الأولى هي بناء دائرة تصميم برج تسلا وقياس الكفاءة الممكنة التي يمكن الحصول عليها. المهمة الثانية لمشروعنا هي بناء دائرة مغناطيسية مقترنة تعتمد على فكرة تقنية الشحن اللاسلكي للهواتف النقالة, من خلال تجاربنا درسنا كفاءة الطاقة وتأثير كل من المسافة بين المرسل والمستقبل وكذلك قطرالملف وعدد لفات الملف على الكفاءة. لتعزيز نتائجنا ، يُقترح توصيل هذه الدوائر وتصميمها عن طريق المحاكاة باستخدام برنامج ملتي سيم وتحقيق الهدف المنشود.

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Introduction

One of the foremost problems within the existing grid is that the losses occurring within the transmission and allocation of energy to the tip users. the share of loss of power during transmission and distribution is approximated as 26%. the first reason for power loss during transmission and distribution could also be the resistance of wires used for grid. The efficiency of power transmission could also be improved to a specific level by employing high strength composite overhead conductors and underground cables who use warm super conductor. But the transmission is inefficient [1]. Wireless power transfer (WPT), wireless energy transmission (WET), or electromagnetic power transfer is that the transmission of electricity without wires as a physical link. during a wireless power gear, a transmitter device, driven by electrical power from an influence source, generates a time varying electromagnetic field, which transmits power across space to a receiver device, which extracts power from the sphere and supplies it to an electrical load. Wireless power transfer is helpful to power electrical devices where interconnecting wires are inconvenient, hazardous, or don't seem to be possible. [2] The possible applications of Wireless power systems extend from wireless charging of portable devices like phones, electric tooth brush using principal of inductive coupling, and other consumer devices to higher power applications like electric vehicles. [3] Many researches have contributed to build and design such systems. In [4], Authors presented the concept of transmitting power without using wires i.e. transmitting power as microwaves from one place to a different so as to cut back the value, transmission and distribution losses increase efficiency. It's got wireless power transmission provides greater power transfer potential with negligible losses. it had been proved that the ability transmission efficiency can approach near 100%. within the long term, this may reduce our society's reliance on batteries, which are currently heavy and expensive. [4] At the same year, researchers in [5] presented a search supported circuits working as WPTS. All the circuits are using sets of two magnetically coupled coils whose parameters were extracted by simulations specialized software ANSOFT Q3D EXTRACTOR. The simulations of the circuits were performed using TINA, SPICE and SIMULINK in MATLAB , they concluded that WPTS are more appropriate for tiny distances transmission, distances up to twice the coils dimensions, because the flux strength produced by the transmitter becomes very weak when the space increases. They said that the efficiency of the system can reach up to 95% for brief distance.[5] In [6] researchers can find out that the resonance frequency depends on the electrical details of the circuit that are hard to predict. varying the coil distance of the transmitter, and the receiver can affect the brightness of the LEDs/lamps or the rotation velocity of the propeller. They find that the propeller can be driven even when the coils are set to the maximum distance of 24 cm. [6]

Theory and calculation

In general a wireless power grid consists of a "transmitter" device connected to a source of power as shown in fig.1, like a main line, which converts the ability to a time-varying electromagnetic field, and one or more "receiver" devices which receive the facility and convert it back to DC or AC electrical phenomenon which is employed by an electrical load. [7]

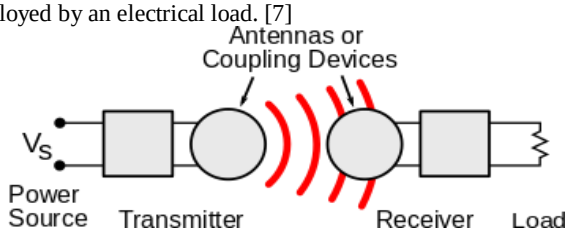


Fig. 1 Generic block diagram of a wireless power system

At the transmitter the input power is converted to an oscillating electromagnetic field by some sort of "antenna" device. The word "antenna" is employed loosely here; it's going to be a coil of wire which generates a flux, a metal plate which generates an electrical field, an antenna which radiates radio waves, or a laser which generates light. A similar antenna or coupling device at the receiver converts the oscillating fields to an electric current [8]. An important parameter that determines the type of waves is the frequency, which determines the wavelength. In near field or non radiated techniques, by magnetic fields using inductive coupling between coils of wire, power is transferred over short distances, or by electric fields using capacitive coupling between metal electrodes [9]. The far-field techniques are used to measure the electrical load far from the power source. These techniques can be divided to two categories, which are microwave power transmission and laser power transmission [10].

The formula to compute input power of the circuit is:

$$P_{in} = \frac{V_{tr} I_{tr}}{\sqrt{2}} \text{ ----------(1)}$$

Where I_{tr}: transmitted circuit current in (A), P_{in}: transmitted power in watts (W), V_{tr}: transmitted circuit voltage in volts (V),

The formula for the output power of the circuit is:

$$P_{out} = \frac{V_r I_r}{\sqrt{2}} - - - - - - (2)$$

Where I_r :received circuit current in amperes (A), P_{out}: output power in watts (W), V_r: received circuit voltage in volts (V),

The efficiency is defined as:[6]

$$\zeta = \frac{P_{out}}{P_{in}} \text{ ----------(3)}$$

Materials and Methods

As any system it's important to clarify the main requirements for design and perform a compact system. One of these is 555 Timer, BJT transistor, MOSFET transistor.

A. 555Timer

The 555 timer could be a one form of chip employed in different applications like an oscillator, pulse generation, timer. The designing of IC555 timers is done by using various electrical and electronic components like transistors, resistors, diodes and flip flops. The operating range of this IC from 4.5V-15V DC supply. The functional parts of the 555 timer IC include flip-flop, potential divider and a comparator. the most function of this IC is to come up with an accurate timing pulse. In mono stable mode of 555timer, the delay is controlled by the external components sort of a resistor and capacitor. In astable mode, both the duty cycle and frequency are controlled by two external resistors and one capacitor, as it's desired during this research.[11] The 555 timer IC consists of 8-pins where each pin has specific function as shown in fig.2.

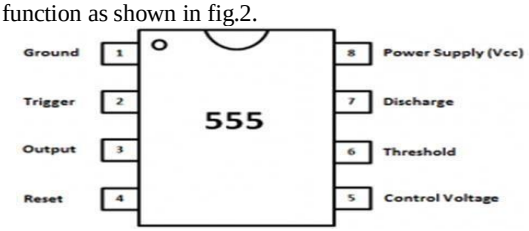


Fig. 2: Pin Configuration of 555Timer IC

The 555 Timer has astable operating mode, it is implemented using two resistors, R1,R2, and one capacitor C as shown in fig.3.

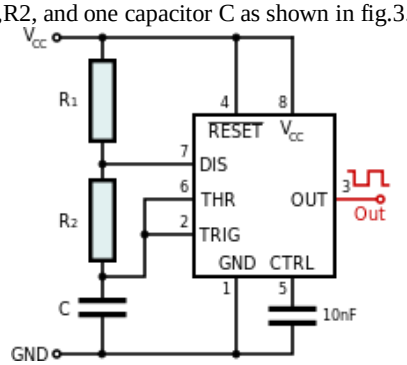


Fig. 3: Schematic of a 555 timer in astable mode.

The high time interval T_{high} of each pulse is given by:

$$T_{high} = \ln(2).(R_1 + R_2).C - - - - - - (4)$$

The low time interval T_{low} of each pulse is given by:

$$T_{low} = \ln(2).(R_2).C - - - - - - - - - - (5)$$

Hence, the frequency of the pulse is given by:

$$f = \frac{1}{T_{high}+T_{low}} = \frac{1}{\ln(2).(R_1+2R_2).c} \text{ ----------(6)}$$

The duty cycle (%) is given by:

$$\text{duty cycle} = \frac{T_{high}}{T_{high+T_{low}}} \text{ ---------- (7)}$$

where t is in seconds (time), R_1,R_2 are in ohms (resistance), C is in farads [12]

B. MOSFET

The word MOSFET symbolizes: Metal-Oxide-Semiconductor-Field–Effect-Transistor A so-called isolated network transistor is a type of field effect transistor with a transport channel whose internal structure depends on semi-conductive materials. It consists of three limbs: source, drain, and gate. The solvent relies on the voltage difference between the gate and the source to allow the electric current to pass from the source to the drain unlike the normal transistor, which relies on the electric current to operate it to work in turn a key or amplifier for electrical signals as shown in fig.4 [13]

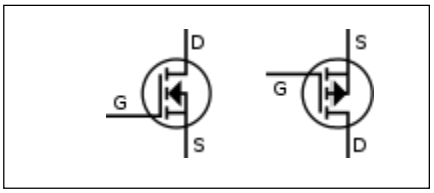


Fig.4: Schematic symbols of P channel and N channel MOSFET

C. BJT transistor

A bipolar junction transistor (BJT) may be a style of transistor that uses both electrons and electron holes as charge carriers. A bipolar transistor allows a tiny low current injected at one among its terminals to regulate a far larger current flowing between two other terminals, making the device capable of amplification or switching as shown in fig.5 [14]

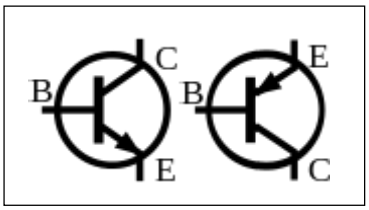


Fig.5: BJTs NPN and PNP schematic symbols

System Design

This part is to design wireless power transfer system, relying using inductive coupling circuit and magnetic resonance circuits where the work was divided into two experiments, the first one is designed to verify theory of Tesla tower, where it's realizing the theoretical facts and and lighting LED bulb wirelessly with efficiently. Next it's designed an induction circuit that achieves the idea of wireless charging technique at short distance and being able to transfer energy wirelessly with high performance system.

A. Tesla Tower Task

Based on Tesla Tower idea, it's possible to design the electronic circuit that can transfer the power wirelessly to the load using inductive coupling circuit. The circuit design is shown in fig.6

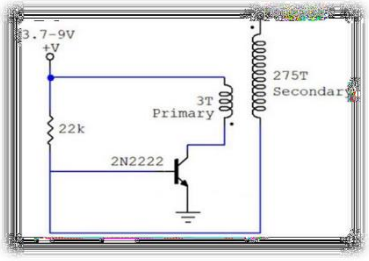


Fig. 6: The connection circuit of Tesla Tower experiment.

B. Circuit Timer Test

In this section, it's chosen 555 timer chip in mono stable mode in the connection circuit shown in fig. 7 and fig. 8 shows the practical connection of 555Timer in mono stable mode. the time interval is controlled by the values of resistors R1, R2 and capacitor C to elapse. When the 555 is sent a trigger pulse, this stable state is temporarily interrupted for an interval that's determined by the value of a resistor and a capacitor. During this interval, the output at pin 3 goes high, but once the time interval has passed, the 555 returns to its stable state, with pin 3 going low [14].

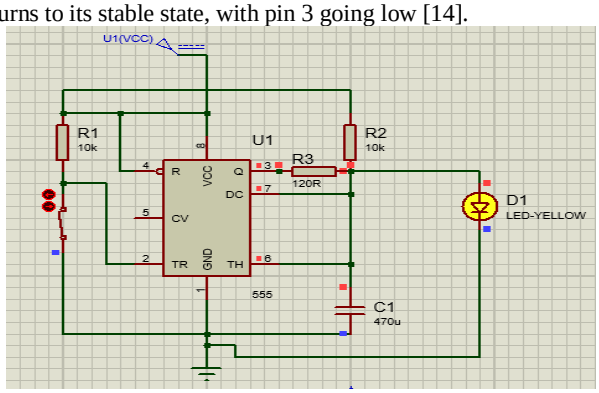


Fig. 7: Connection circuit of 5555 timer in Mono stable mode.

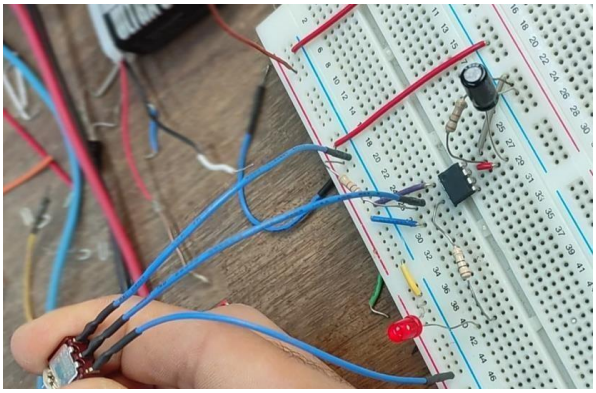


Fig.8: Practical connection circuit for switching LED using 555Timer

C. Wireless mobile charging Task:

This part is trying to transfer power wirelessly to charge low power devices, such as mobile phones, cameras, wireless mouse etc. This circuit consists of three main blocks at transmitter Tx, oscillator circuit represented by a Timer to produce AC signal, and the receiver Rx. The connection circuit is shown in fig.9. 555Timer is producing a pulse through timing components such as resistors and capacitors. The pulse is generated from IC which is fed into the transistor through 500Ω resistor. The signal is then amplified by two transistors, one is NPN and the other PNP This formation is called Push-Pull Amplifier Circuit [12].

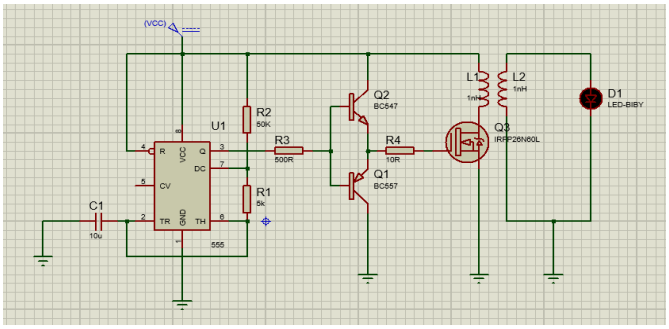


Fig.9: Connection circuit of wireless charging system.

Results and Discussion

A. Tesla tower circuit

When Operating the circuit and switching the power supply, the electric current is passing through primary coil that generates high voltage at the secondary coil as a result of the magnetic flux and induced voltage at the primary. If it's attached LED bulb it will be high illuminated because of transfer maximum power to the receiver as shown in fig.10. It's found that this power reduces as the distance increases as in table-1, it can be reached up to 70% efficiency at short distance about 6 cm distance. Graph of power and distance is shown in fig.11.

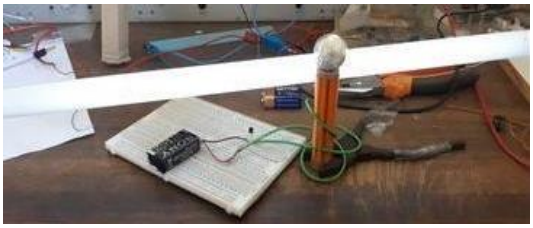


Fig.10: The practical circuit connection of Tesla Tower.

Table-1 the relationship between the distance and efficiency.

Distance	Efficiency
Near or Attached	High
5cm	Medium
10cm or above	Low

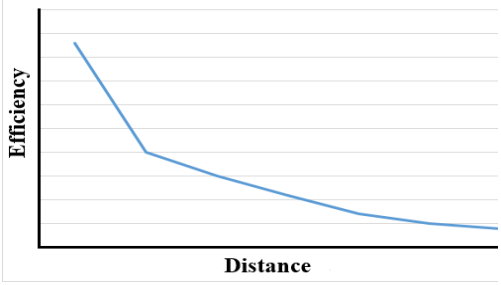


Fig.11: The graph of power efficiency vs distance.

B. 555 Timer test circuit

With the trigger input high, the output voltage at pin 3 is near zero. When the pushbutton switch is depressed, the provision voltage is short- circuited to ground. This causes the voltage at pin 2 to drop to zero, and also the timer is triggered. Once the timer is triggered, the output voltage at pin 3 goes high and also the timing interval begins. during a nutshell, once the circuit is triggered, C1 begins to charge. Pins 6 and seven the edge and discharge pins are tied together in an exceedingly mono stable 555 circuit. Pin 6 watches the voltage across the capacitor. because the capacitor charges, this voltage increases. When the capacitor voltage reaches two thirds of the Vcc supply voltage, the timing cycle ends, and also the output at pin 3 goes low. When the output is high, the switch is open; when the output is low, the switch is closed. When the switch is closed, alittle 10 Ω resistor within the 555 connects pin 7 to ground. this can be clarified as in fig.12 [13].

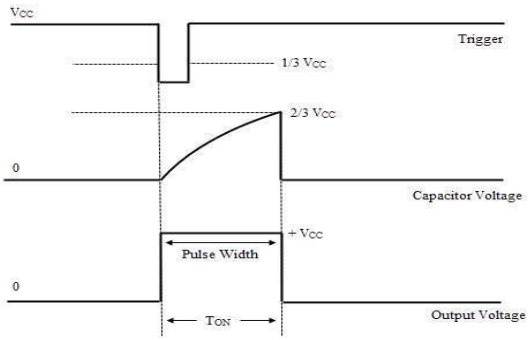
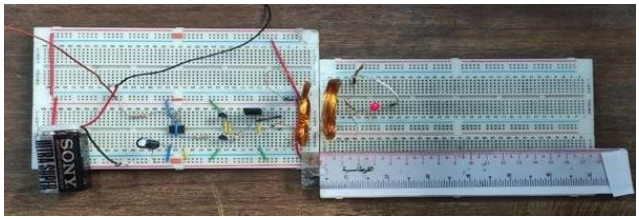


Fig.12: The waveforms of the mono stable operation

C. Wireless charging mobile:



it's noticed that when the coil at RX is attached to TX it or at short distance about 2cm will get max power transfer to LED (see fig.13) ,if the distance increased to about 10cm there will be no output power at RX (see fig.14) .

Fig:13: Practical connection circuit at short distance, LED is ON.

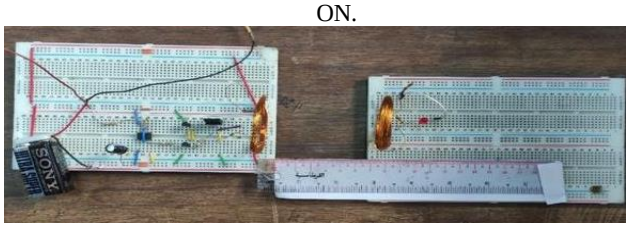


Fig.14: connection circuit when increasing distance LED is OFF.

It's noticed that there are relations between efficiency, number of turns ratio n, and the coil diameter d as in table-2 and table-3 respectively. Fig.15 show the graphical representation of the current and voltage vs distance and diameter. Fig. 16, and fig.17 show the practical connection circuit for different relationships.

Table-2: Relationship between current i and turns ratio n when coil diameter d=4.5cm

	distance(cm)	0	1	3	6	9	12
n=28	current(mA)	14	4	1.02	0.11	0.02	0
n=50	current(mA)	20	10	1.5	0.17	0.01	0

Table-3: Relationship between Voltage and Diameter at turns ratio N =31turns.

Diameter (cm)	Voltage (Vpp)
4.5	4
10	6.5

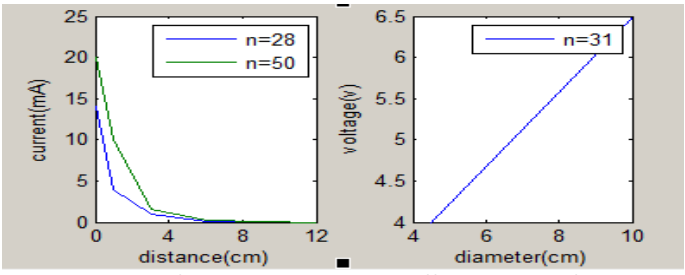


Fig.15: Graph of Current vs distance at different values of turns ratio N and coil diameter 4.5cm (left). Graph of voltage vs diameter at the n=31 and fixed distance (right).

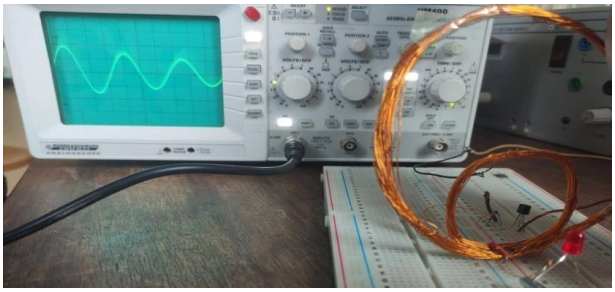


Fig.16: Practical connection circuit at diameter =4.5cm, n =31turns.

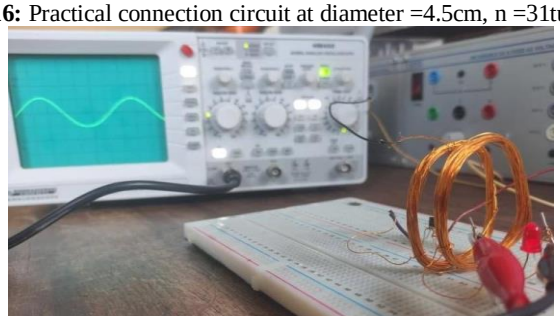


Fig.17: Practical connection circuit at diameter =10cm, n =31turns.

From the previous results it's concluded that the efficiency increases as the radius and number of turns increase while it will decrease as more distance. It's used pure copper to make the coils with different diameters and thicknesses, When using thick wire 1mm, a higher power transmission is compared to thin wire 0.25mm, And when the number of turns and diameter increase, it would get more efficiency at the output, because of increasing the turns will enhance the magnetic field that causes to generate the induced voltage at the secondary winding. when the distance is lower than 10 cm, the efficiency reaches up to 70%. Inductive Coupling method helps us to transfer Energy using Magnetic flux but it is possible for few inches only, it may increase in near future. Based on experimental results, the study on wireless power transfer using inductive coupling has much aspect in terms distance, range of frequency and results show that nearer the distance, higher Current transferred. The wireless power transfer is not much affected by shielding materials such as the presence of hands, books and types of plastics.

Conclusion:

This paper has discussed wireless power transmission technology and its various applications in our life. Moreover, it's presented the potential implementation of wireless power transfer technology to make our life easier. This work is to prove theoretical aspects like Tesla Tower theory, wireless charging mobile depending on practical connection circuits using 555Timer and other electronic components like BJT and MOSFET transistors. It's also made simulated circuits using Multisim and proteus software design. At sum, the efficiency of such systems dependent on the distance the coil turns and radius of it, it's got maximum power transfer with low space between Tx and Rx as appropriate coil geometrical design.

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